Nanoparticle Structure from Focal-Series Reconstruction of the Specimen Exit-Surface Electron Wave with Sub-Ångstrom Electron Microscopy

Michael A. O'Keefe*, E. Chris Nelson# and Lawrence F. Allardº

*Materials Science Division, LBNL 2R200, 1 Cyclotron Road, Berkeley, CA 94720, USA

#Materials Science Division, LBNL 72R150, 1 Cyclotron Road, Berkeley, CA 94720, USA

ºHTML, ORNL, Building 4515, MS6064, 1 Bethel Valley Road, Oak Ridge, TN 37831-6064, USA

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M.A. O'Keefe*, Z. Liliental-Weber¶, E.C. Nelson#, T. Tomaszewicz¶ and L.F. Allardº
*Materials Science Division, LBNL 2R200, 1 Cyclotron Road, Berkeley, CA 94720, USA
¶Materials Science Division, LBNL 62R213, 1 Cyclotron Road, Berkeley, CA 94720, USA
#Materials Science Division, LBNL 72R150, 1 Cyclotron Road, Berkeley, CA 94720, USA
ºHTML, ORNL, Building 4515, MS6064, 1 Bethel Valley Road, Oak Ridge, TN 37831, USA

Abstract

Identifying atom positions in nanomaterials requires appropriate resolution, i.e., the ability to separate distinct objects in images [1]. Heavy (metal) atoms can be routinely imaged in TEM specimens at resolutions from 2Å to 1.5Å. Better resolutions (nearer to 1Å) are required to “see” lighter atoms such as carbon [2], nitrogen [3] and even lithium [4]. The one-Ångstrom microscope (OÅM) project [5] exceeds its 1.7Å Scherzer resolution [6] to reach better than one-Ångstrom at 300keV by using a combination of a modified CM300FEG-UT with computer software [7,8] able to correct C_S and generate sub-Ångstrom images from experimental image series. The OÅM has demonstrated that a resolution of 0.78Å is possible with this technique [9].

The OÅM was designed to use focal-series reconstruction to achieve sub-Ångstrom resolution in order to allow imaging of light atoms in the presence of heavy metal atoms [5]. There has been concern that the focal series reconstruction method might be difficult to apply to severely non-periodic specimens such as nanoparticles with their strong Fresnel fringes. As a test of the technique, we have used the OÅM to produce an image of the exit-surface wave (ESW) of a 70Å particle of gold supported on amorphous carbon by applying focal-series reconstruction (FSR) to a series of 20 images obtained at focus values ranging from –2600Å to –2144Å. The phase of the complex ESW shows the positions of the atom columns in the specimen as white dots with phases proportional to the number of atoms in each column, clearly demonstrating five-fold twinning that is not visible in the Scherzer image at a resolution of 1.7Å.

The result demonstrates that through-focal reconstruction of the ESW can work properly when the component images have strong Fresnel fringing. Although Au structures may not need sub-Å resolution to show all the useful structural details of particles in [110] orientation, it is clear that focal series reconstruction of the ESW can substantially improve original data that is much more difficult to interpret directly. We expect this technique to prove even more useful when applied to particles containing finer spacings than those present in gold nanoparticles [10].

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